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Changes in breathing pattern and thoracoabdominal motion after bariatric surgery: A longitudinal study

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ABSTRACT

This study evaluated the breathing pattern of 30 obese patients [32 ± 9 years old; body mass index (BMI): 42.72 ± 4.10 kg/m^2] before and after bariatric surgery and compared them with 30 control individuals (31 ± 8 years old, BMI: 21.99 ± 2.22 kg/m^2). Measurements were performed using calibrated respiratory inductive plethysmography. Six months after bariatric surgery, obese patients exhibited a significant reduction in tidal volume (V_T), minute ventilation (V_E) and inspiratory duty cycle (T_I/T_{TOT}) compared with pre-surgical values. The control group had a higher breathing frequency, V_E and phase angle (PhAng). There were no significant differences in V_T/T_I, percentage of rib cage motion (%RC) or abdominal motion (%AB). Obese patients exhibited changes in their breathing pattern and asynchrony after bariatric surgery without any changes in thoracoabdominal motion. Certain aspects of the breathing pattern of obese patients became more similar to those of the controls after surgery.

1. Introduction

Obesity is a chronic disease characterized by the excessive accumulation of corporal fat and is one of the most serious problems in public health today, considered an international epidemic (Mancini, 2001).

The World Health Organization (1998) classifies obesity using the body mass index (BMI), (Deurenberg et al., 1991). In obesity grade I, the BMI is 30–34.9 kg/m^2; in grade II, it is between 35 and 39.9 kg/m^2 and in grade III, or morbid obesity, the individual has a BMI above 40 kg/m^2 (Associação Brasileira para o Estudo da Obesidade e da Sindrome Metabólica, 2009).

Due to the inefficacy of dieting and the frequency of recurrences following pharmacological treatments, stomach reduction surgery is one of the most effective methods for treating grave obesity. Today, most surgeons perform gastric bypass surgery using the “Roux en Y” technique proposed by Fobi and Capella (Capella and Capella, 2002). This surgery is considered the “gold standard” because of its efficiency and low morbidity and mortality (Fisher and Schauer, 2002).

The main benefit of bariatric surgery is its maintenance of weight reduction. Patients lose from 40% to 75% of their excess weight. Even more significant than the weight reduction is the surgery’s impact the diseases associated with obesity (Choran et al., 2002; Kress et al., 1999; Wadstrom et al., 1991; Weiner et al., 1998). This was confirmed in a meta-analysis that demonstrated a reduction of 61.6% in average of excess weight loss associated with reduced blood glucose levels, total cholesterol level, hypertension and obstructive sleep apnea level (Buchwald et al., 2004).

Literature about pulmonary function in obesity is primarily concerned with the analysis of volumes and capacities during spirometry. Chlif et al. (2009) found that forced expiratory volume in 1 s (FEV$_1$) and forced vital capacity (FVC) were significantly reduced in obese patients compared to controls. Thomas et al. (1989) and Weiner et al. (1998) found increased total lung capacity (TLC), functional residual capacity (FRC), expiratory reserve volume (ERV) and residual volume (RV) 6 and 26 months after bariatric surgery. Martí-Valeri et al. (2007) demonstrated improvement of hypoxemia, hypercabia, FEV$_1$, FVC at 1 year after the surgery (Martí-Valeri et al., 2007)

To the best of our knowledge, only one study has examined the breathing pattern of obese patients at rest. Chlif et al. (2009) found that tidal volume, frequency, minute ventilation, and inspiratory

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duty cycle were significantly higher in an obese group than in non-obese controls, without changes in mean inspiratory flow. Changes in breathing pattern after bariatric surgery has not yet been explored and established. On the other hand, the variables related to thoracoabdominal motion asynchrony of breathing are unknown in obese that underwent bariatric surgery or not. We hypothesize that surgery can promote positive changes in breathing pattern and thoracoabdominal motion parameters contributing to a higher respiratory efficiency.

The main purpose of this study was to perform a longitudinal evaluation of breathing pattern, volume and time variables and to measure the thoracoabdominal motion of obese patients before and at 1 and 6 months after bariatric surgery, comparing these patients to a control group of non-obese individuals matched by sex and age.

2. Materials and methods

2.1. Sample

Two groups of individuals took part in this study: Group I consisted of obese patients selected from a list of patients scheduled for bariatric surgery in Vila da Serra Hospital, Belo Horizonte-MG, Brazil. Group II, the control group, was composed by individuals with BMI values within the normal range, who were recruited from the community and matched by sex and age. The inclusion criteria for Group I were obesity grade II or III, a scheduled bariatric surgery within 7 days using the Rous en Y technique, age between 18 and 60 years, no clinical history of cardiopulmonary disease, and no cognitive alterations. The exclusion criteria were as follows: postoperative complications requiring more than 24 h of mechanical ventilation or which did not accomplish the proposed measures. Inclusion criteria for the control group were age between 18 and 60 years, BMI value between 18 and 29.9 kg/m^2, normal spirometric values, no history of cardiopulmonary diseases, no cognitive alterations that would interfere with the evaluation procedures, no current or prior history of smoking and no previous abdominal surgical procedures. The study was approved by the Ethics Committee of the Institution, and all individuals gave informed, written consent.

2.2. Signals and measurement

Functional analysis of lung volume and capacity was carried out using a portable spirometer (Vitalograph 2120®, Buckingham, England). Criteria for acceptance and reproducibility were observed. The values of the spirometric variables were compared to predicted values according to published Pereira values (Pereira, 2002).

Respiratory inductive plethysmography (Respitrace®, Nims, Miami, FL, USA) was used to assess breathing patterns and to measure thoracoabdominal motion. The accuracy of plethysmography in the evaluation of breathing patterns has been determined at rest and during physical activity in both adults and children (Chadha et al., 1982). Tidal volume measurements are satisfactory as long as the body position remains constant after the calibration procedure (Chadha et al., 1982). The system consists of two bands (Teflon®-coated inductance bands) that measure changes in the cross-sectional area of the rib cage (RC) and abdomen (AB). Bands of appropriate size were placed around the RC and AB; the upper edge of the RC band was placed at the level of the axilla, and the abdominal band was placed at the level of the umbilicus. Signals were calibrated using qualitative diagnostic calibration (QDC) (Sackner et al., 1989) during natural breathing. This method is a two-step procedure whereby the rib cage and abdominal electrical gains of the respiratory inductive plethysmography amplifiers are correctly partitioned during tidal breathing and are subsequently the output of the spirometer was adjusted to correspond to the plethysmograph values. The subject subsequently breathed into a spirometer using a mouthpiece (Vitatrace, Pro Médico, Rio de Janeiro, RJ, Brazil) with the nose clipped for 30–60 s, and the electrical spirometer output was recorded with a computer and was used to calibrate the respiratory inductive plethysmographic sum signal for absolute volume in ml. The spirometer was calibrated with a 1-liter syringe (Vitalograph, Buckingham, England) using computer software (RespiPanel 4.0, Nims), and signals were recorded with a digital acquisition system (RespiEvents 5.2, Nims). Transcutaneous oxygen saturation (SaO_2) and pulse rate were recorded by pulse oximetry (Datex-Ohmeda Inc., Louisville, CO, USA) using a finger probe (Bloch et al., 1995; Sackner et al., 1989).

2.3. Analyzed variables

The following variables were measured using a digital acquisition system on a breath-by-breath basis: tidal volume (V_T), respiratory frequency (f), minute ventilation (V_E), inspiratory duty cycle (T_I/T_{TOT}), mean inspiratory flow (V_T/T_I), percentage of rib cage motion (%RC), percentage of abdomen motion (%AB = 100 − %RC) and phase angle (PhAng). The PhAng is related to thoracoabdominal motion and reflects the delay between RC and AB excursions: values range from 0° (perfect synchrony) to 180° (paradoxal movement). After 30 min of recording, 6–10 min of steady-state readings were selected for analysis.

2.4. Procedures

Initially, obese patients were interviewed to fill an identification register with previously collected individual spirometric data. The individuals lay comfortably on a flat bed in a supine position to record their breathing pattern and thoracoabdominal motion. One pillow was placed under the head and another under the knees. Oxygen saturation and pulse rate were registered. The QDC method was applied, and the individual remained in this position for about 30 min. The preoperative variables were collected no more than 7 days before surgery. The procedure was repeated in Group I at 1 and 6 months after surgery (approximately 4 days).

The procedures for the control group were the same as those used for the obese patients. However, their BMI was also verified to ensure inclusion criteria. The control group was analyzed only once.

2.5. Statistical analysis

Data are reported as means ± standard deviation. A distribution analysis was performed using the Kolmogorov–Smirnov test. To compare demographic, anthropometric and spirometric data between Group I and Group II subjects, a Student's t-test for unpaired samples was used when the distribution was considered normal and a Mann–Whitney U when the distribution was not normal. For BMI, breathing pattern and thoracoabdominal motion variables, comparisons between preoperative and postoperative (at 1 and 6 months after sugery) values were performed using a repeated measures ANOVA followed by Tukey's *post hoc* test when the distribution was normal; the Friedman and Wilcoxon tests were used when the distribution was not normal. The level of significance (α) was set at 0.05 (two-tailed) for all tests. For variables analyzed by ANOVA, the power of the results was also calculated (Portney and Watkins, 2000). Data were analyzed using the Statistical Package for the Social Sciences software (SPSS 13.0, Chicago, IL, USA).

3. Results

Thirty-one individuals were selected for this study; nine of them had obesity grade II, and 22 exhibited obesity grade III. One patient with obesity grade III was excluded, due to complications during the anesthetic induction that interrupted the surgery. Therefore, 30 obese patients were studied. Thirty non-obese individuals matched for sex and age were selected as the control group.

A total of 20885 respiratory cycles were analyzed, including 15693 cycles of obese patients (5495 preoperatively, 5036 one month after surgery and 5162 six months after surgery). Although 90 steady state traces were initially planned (3 on each of the 30 patients), only 81 were conducted. The missing traces included four traces discarded for exhibiting artifacts and excess irregularities, one trace not collected because of non-attendance at the 1-month-postoperative visit and four traces not collected because of non-attendance at the 6-month-postoperative visit). In the control group, 5192 cycles were analyzed.

Table 1 shows the demographic, anthropometric and spirometric data of both groups. No significant differences were observed in age, sex, height, pulse rate or SaO_2. Obese patients exhibited weight values and BMI values that were significantly higher than those of the control group. When compared to the control group, the obese patients had significantly higher FVC and FEV_1, but both groups exhibited predicted values within normal limits.

Three individuals were former smokers, and the others were nonsmokers. All of these individuals were sedentary. In the control group, five individuals performed regular physical activity.

Table 1
Demographic, anthropometric and spirometric data of obese patients before surgery (preoperative levels) and the non-obese control group.

Variables	Patients group (n = 30)	Control group (n = 30)	p value
Gender	24 female:6 male	24 female:6 male	–
Age (years)	32.37 ± 8.5	30.60 ± 7.76	0.405
Height (m)	1.67 ± 0.11	1.67 ± 0.10	0.970
Weight (kg)	120.13 ± 24.32	62.11 ± 11.68	0.001*
BMI (kg/m^2)	42.72 ± 4.10	21.99 ± 2.22	0.001*
HR (bpm)	74.73 ± 11.77	70.97 ± 9.10	0.171
SaO_2 (%)	96.36 ± 1.35	96.87 ± 1.38	0.185
FEV_1 (%pred.)	117.47 ± 29.99	95.89 ± 9.09	0.005*
FVC (%pred.)	119.12 ± 34.18	97.93 ± 9.36	0.045*

Data are presented as means ± standard deviation. BMI: body mass index; HR: heart rate; SaO_2: transcutaneous oxygen saturation; FEV_1: forced expiratory volume in the first second; FVC: forced vital capacity; %pred.: % predicted. Student's t-test for independent groups was used (age, height, weight, BMI) or Mann–Whitney U (SaO_2, FEV_1 and FVC) according to data distribution. p refers to the significance level.

Table 2 shows the data related to BMI and breathing pattern variables of patients before and at 1 and 6 months after surgery as well as those of the control group. There were significant and progressive reductions in BMI after the surgery, although the values were higher than those of the control group (p = 0.000 for all comparisons). Tidal volume exhibited a significant decrease postoperatively compared to the preoperative recordings (p = 0.01) but without any differences between measurements at 1 and 6 months postoperatively. There were no differences in tidal volume between patients and the control group. There were no consistent changes in the f of Group I during the postoperative

Table 2
Body mass index and breathing pattern of obese patients before surgery and at 1 and 6 months after the bariatric surgery and of the non-obese control group.

Variables	Control group (n = 30)	Preoperative (n = 27)	After 1 month (n = 28)	After 6 months (n = 26)	p Power
BMI	21.99 ± 2.22	42.72 ± 4.10^a	38.51 ± 3.65^a	31.77 ± 4.20^{a,b,d}	0.001 1
V_T (ml)	362.28 ± 104.6	402.16 ± 181.54	380.61 ± 239.14^b	346.76 ± 253.09^c	0.001 –
f (bpm)	15.25 ± 3.66	18.71 ± 5.29^a	17.78 ± 5.85	18.94 ± 4.84^a	0.005 0.903
V_E (l/min)	5.22 ± 0.98	6.79 ± 1.71^a	5.87 ± 2.17^b	5.73 ± 1.85^c	0.000 0.978
T_I/T_{TOT}	0.41 ± 0.04	0.42 ± 0.04	0.41 ± 0.04^b	0.41 ± 0.04^c	0.003 0.935
V_T/T_I (ml/s)	215.99 ± 50.67	272.22 ± 77.82	240.48 ± 82.60	232.52 ± 74.57	0.022 0.748

Data are presented as means ± standard deviation. BMI: body mass index; V_T: tidal volume; f: respiratory frequency; V_E: minute ventilation; T_I/T_{TOT}: inspiratory duty cycle; V_T/T_I: mean inspiratory flow. Comparisons were performed with ANOVA for repeated measures, followed by Tukey's test (V_E, f, T_I/T_{TOT}, V_T/T_I) or Friedman test followed by Wilcoxon's test (V_T), according to each data distribution. Statistically significant differences:
[a] Obese patients preoperatively and at 1 and 6 months after surgery *versus* control group.
[b] Obese patients at 1 month after surgery *versus* preoperative obese patients.
[c] Obese patients at 6 months after surgery *versus* preoperative obese patients.
[d] Obese patients at 6 months after surgery *versus* obese patients at 1 month after surgery. p refers to the significance level relative to the test analysis (ANOVA or Friedman) and Power refers to the power of variables analyzed by ANOVA.

Table 3
Thoracoabdominal motion variables of obese patients before surgery and at 1 and 6 months after the bariatric surgery and of the non-obese control group.

Variables	Control group (n = 30)	Preoperative (n = 27)	After 1 month (n = 28)	After 6 months (n = 26)	p Power
%RC	37.72 ± 11.25	28.67 ± 11.49	29.28 ± 11.34	35.63 ± 13.97	0.044 0.652
%AB	62.28 ± 11.25	71.33 ± 11.49	70.72 ± 11.34	64.37 ± 13.97	0.044 0.652
PhAng (°)	10.42 ± ±6.49	26.19 ± 23.87^a	29.50 ± 33.69^a	20.63 ± 25.41	0.005 –

Data are presented as means ± standard deviation. %RC: percentage of the rib cage motion; %AB: percentage of the abdomen motion; PhAng: phase angle. Comparisons were performed with ANOVA for repeated measures, followed by Tukey's test (%RC and %AB) or a Friedman's test followed by Wilcoxon's test (PhAng), depending on the distribution of each variable. Statistically significant differences:
[a] Obese patients preoperatively and at 1 and 6 months after surgery versus control group.
[b] Obese patients at 6 months after surgery versus preoperative obese patients; p refers to the significance level relative to the test analysis (ANOVA or Friedman) and power refers to the power of two variables analyzed by ANOVA.

period. A higher f was observed preoperatively and 6 months after surgery when compared to the control group ($p = 0.008$ and $p = 0.01$, respectively). Minute ventilation exhibited a significant decrease at the postoperative measurements compared to the preoperative measurements ($p = 0.01$) without any differences between 1 and 6 months. In the control group, V_E was higher than in the preoperative obese patients ($p = 0.004$). The T_I/T_{TOT} values of obese patients exhibited a significant decrease at the postoperative measurement compared to the preoperative measurement ($p = 0.01$) but without any differences between postoperative measurements at 1 and 6 months. There were no differences in T_I/T_{TOT} values between patients and the control group. The V_T/T_I comparisons did not show any significant differences ($p = 0.22$).

Table 3 shows the thoracoabdominal motion data of Group I before and at 1 and 6 months after surgery as well as of the control group. Comparisons of %RC and %AB did not show significant differences. No significant changes were observed in the PhAng postoperatively. Values of PhAng were higher than those of the control group both preoperatively and at 1 month after surgery ($p = 0.001$) but were not different from those of the obese patients 6 months after surgery ($p = 0.58$).

4. Discussion

The main findings of this study were that (1) obese patients exhibited a significant decrease in V_T without changes in f, leading to a significant decrease in V_E in the postoperative period associated with a significant decrease in T_I/T_{TOT} 6 months after surgery; (2) compared to the control group, obese patients exhibited significantly higher V_E and PhAng preoperatively, which became more similar to the control group postoperatively; and (3) no changes in V_T/T_I, %RC or %AB in obese patients were observed; also, there were also no differences with respect to the control group in these variables.

The significant decrease in V_E observed postoperatively can be attributed to the decrease in V_T because there was not any significant reduction in f between pre- and post-operative patients. These results are similar to those observed by Dávila-Cervantes et al. (2004) that found a decrease in V_T 1 year after surgery (Dávila-Cervantes et al., 2004). The V_E in the group of obese patients was higher preoperatively than in the control group. These results are similar to those of Chlif et al. (2009) and Cavallazzi et al. (1981), who found the V_E of obese individuals was above the normal limit. The higher V_E in the preoperative patients can be attributed to the adverse effects of obesity on pulmonary function, which is directly related to the presence of fat in the rib cage and to the blood redistribution to the thoracic compartment from compression of the abdominal viscera, which causes a reduction in thoracic compliance (Harik-Khan et al., 2001). The overload imposed by the adipose tissue on the rib cage can increase the effort needed to breathe and the energy needed to expand the lungs of obese individuals (Naimark and Cherniak, 1960). Another aspect of respiration in obese patients is their need to keep ventilation and respiratory frequency constant against the increased load, which leads to a constant inspiratory straining and, possibly, to an increased force by the inspiratory muscles (Domingos-Benício et al., 2003; Rochester and Enson, 1974). This increased force would require the maintenance of or increase in V_T and V_E. From this perspective, the weight reduction after surgery could explain the reduction in V_T and V_E found in this study and could be considered an improvement in respiratory function.

However, compared to the control group, the higher V_E observed in preoperative obese patients is related to a higher f because there was not a significant difference in V_T. Tomich et al. (2010) found a lower f during incentive spirometry with a volume-oriented device because this device increased the minute ventilation in obese patients after gastroplasty. Tobin et al. (1983a) demonstrated that individuals with reduced pulmonary compliance increase f to obtain adequate ventilation. This adaptation mechanism probably occurred in our patients. Six months after surgery, there was a significant reduction in V_E despite a higher f than in the control group. This reduction is probably related to a small increase in the ventilation demand despite the significant reduction in BMI; individuals remained obese 6 months after surgery. In the presence of increased ventilatory requirements, there are increases in V_T of up to 60% of vital capacity. Any other ventilation increase is related to an increase in f (Cherniack, 1995). Therefore, it is possible that this difference in f is related to increase respiratory impedance.

The reduction observed in T_I/T_{TOT} postoperatively could be a response to the reduced compliance of the thoracic wall, which was lowest preoperatively and could be responsible for higher impedance within the respiratory system (Koenig, 2001; Naimark and Cherniak, 1960; Zerah et al., 1993). The absence of any difference in T_I/T_{TOT} between obese patients and controls can be explained by the progressive adaptation of the respiratory system as weight increases. According to Domingos-Benício et al. (2004), individuals who have been obese for a long time can adapt to the overload imposed by the adipose tissue.

There were no significant differences in V_T/T_I between the two groups. According to Tobin et al. (1983b), the V_T/T_I ratio reflects the respiratory drive, and obese individuals do not exhibit alteration in ventilatory drive (Sampson and Grassino, 1983). Cavallazzi et al. (1981) evaluated the ventilation of obese individuals after the inhalation of carbonic gas and observed that despite high variability, all individuals showed an adequate response to the stimulus. Chlif et al. (2009) evaluated 34 obese patients and did not find differences in the V_T/T_I from normal values. Weight stabilization usually occurs 1 year after surgery. In this study, patients were only followed for 6 months, which may have influenced the results and is a limitation of this study. Another point to be discussed is that sample size calculated after a pilot study with 10 subjects in each group demonstrated the need of more them 1571 subjects. This number is very high and impossible to be attained on this study. Most of the study related to this field had studied about 30 patients. Moreover, even with only 30 subjects on each group it was possible to verify significant differences in most of the variables, showing a positive effect of the weight loss.

Significant differences were not found in %RC or %AB. Both groups had high levels of abdominal motion, results that corroborate those observed by Tobin et al. (1983b) in normal individuals and those with other respiratory diseases (Tobin et al., 1983a).

The PhAng, a variable that reflects asynchrony on thoracoabdominal motion, has been studied in healthy and patients (Aliverti et al., 2009; Alves et al., 2008; Oliveira et al., 2009; Parreira et al., 2010)

Our results showed that at preoperative period and at 1 month after surgery, obese patients exhibited higher PhAng values than the control group. Tobin et al. (1987) reported that an increased thoracoabdominal asynchrony is associated with an increase in respiratory load, influencing the elastic withdrawal of the rib cage and lungs (Biring et al., 1999; Lazarus et al., 1998). The existence of higher asynchrony 1 month after surgery can be attributed to insufficient weight reduction to decrease the overload to the thoracic wall and, also, to postoperative discomfort because patients were still experiencing some pain and discomfort caused by the surgery (Ford et al., 1993). No significant reduction in PhAng was seen at 6 months after surgery compared to preoperative and after 1 month. One raison for that can be that this variable exhibited greater variability compared to the other variables analyzed.

However, the values were similar to those of the control group, showing an improvement in thoracoabdominal motion.

In conclusion, this study showed that obese patients exhibited significant changes in the majority of studied variables after bariatric surgery. Six months after surgery, there were similarities in the ventilation minute and phase angle when data from patients were compared to data from control-group individuals, suggesting that weight reduction positively influenced the breathing pattern and thoracoabdominal motion of obese patients, contributing to a higher respiratory efficiency.

Conflict of interest

No conflict of interest.

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